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13. ABSTRACT

Methods for determining the fracture resistance of steels using the Drop-Weight Nil-Ductility Transition (DWT-NDT) Test, the Drop-Weight Tear Test (DWTT), and the 5/8-in. Dynamic Tear (DT) test, all by the use of a single vertical impact machine, are described. A vertical impact machine is useful when a limited number of tests are to be conducted, and when cost is an important aspect for determining equipment type. The machine described is of 2000 ft-lb capacity, and two methods for the determination of dynamic tear energy are described. One method employs an oscilloscope trace of the hammer load during the fracture process, and the other method uses the residual kinetic energy of the hammer to compress lead bars. A vertical impact machine is the standard tool (ASTM Standard E208) for conducting the DWT-NDT, and it can be readily modified to conduct the DWTT and the 5/8-in. DT tests.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Drop weight tests Impact tests Mechanical strength Tear tests Dynamic tests Ductility tests Measuring instruments						

ABSTRACT

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PROBLEM STATUS

This report completes one phase of the problem; work on other aspects of the problem is continuing.

AUTHORIZATION

NRL Problem M01-25
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CONTENTS

VERTICAL DROP-WEIGHT MACHINE FOR CONDUCTING DROP-WEIGHT NDT, DROP-WEIGHT TEAR, AND DYNAMIC TEAR TESTS

INTRODUCTION

The metallurgical phenomenon of a fracture toughness transition with temperature has recently gained increasing recognition among engineers as one important aspect of fracture-safe design with the coupling of the results of engineering type tests to the analytical capability of fracture mechanics (1). Although only certain metals and alloys exhibit this behavior, these materials — low and medium yield strength steels, for example — comprise a major portion of production tonnages used in industrial structures. Accurate methods for determining the temperature transition range and the maximum or upper shelf fracture resistance in a given material is therefore an important aspect in fracture-safe design.

A transition in fracture toughness results from an interaction between temperature, strain rate, microstructure, and stress state. Specimen geometry must be such that the mechanical aspects of the test permit the development of correlative predictions of performance in real structures. Procedures for developing the correspondence between structural performance and specimen behavior for the DWT-NDT and DT tests are discussed in Refs. 1 and 2.

At NRL the 5/8-in. dynamic tear (DT) specimen has been studied extensively over the last three years using a double pendulum machine of 2000 ft-lb capacity (3). The double pendulum design results in a smaller machine than a single pendulum design of similar capacity, but its main feature is that it does not transmit a shock to the base mount, which eliminates the need for massive anvil support. The double pendulum machine is adaptable to high production testing of specimens with a fixed geometry. The machine is, however, less versatile than a vertical impact machine for experimental work which involves frequent anvil alteration and variable capacity.

The need to conduct all of the fracture resistance tests associated with the transition temperature phenomenon prompted the development of a vertical impact machine of 2000 ft-lb capacity. The vertical impact machine which was developed readily provides the required versatility with respect to the types of specimens involved. The machine features a removable hammer face to vary striker design and a base for accommodating various anvils. It can be used for conducting the DWT-NDT test (ASTM Standard E208), the NRL 5/8-in. DT test, and the DWTT test for thin sections, which is a new ASTM recommended test method for determining fracture appearance transition temperatures.

MECHANICAL DESIGN PARAMETERS

The essential mechanical features of the vertical drop-weight machine of 2000 ft-lb capacity are illustrated in Fig. 1. The anvil shown is for the 5/8-in. DT specimen. Lead (Pb) bricks placed on either side of the specimen absorb the residual dynamic energy of the hammer after the specimen has been broken and softly stop the falling hammer. The hammer is raised by a motor-driven hoist, and it is released from a specific height by the release mechanism (top). The amount of initial impact energy is chosen with the aid of a suitable scale which indicates the vertical distance through which the hammer must

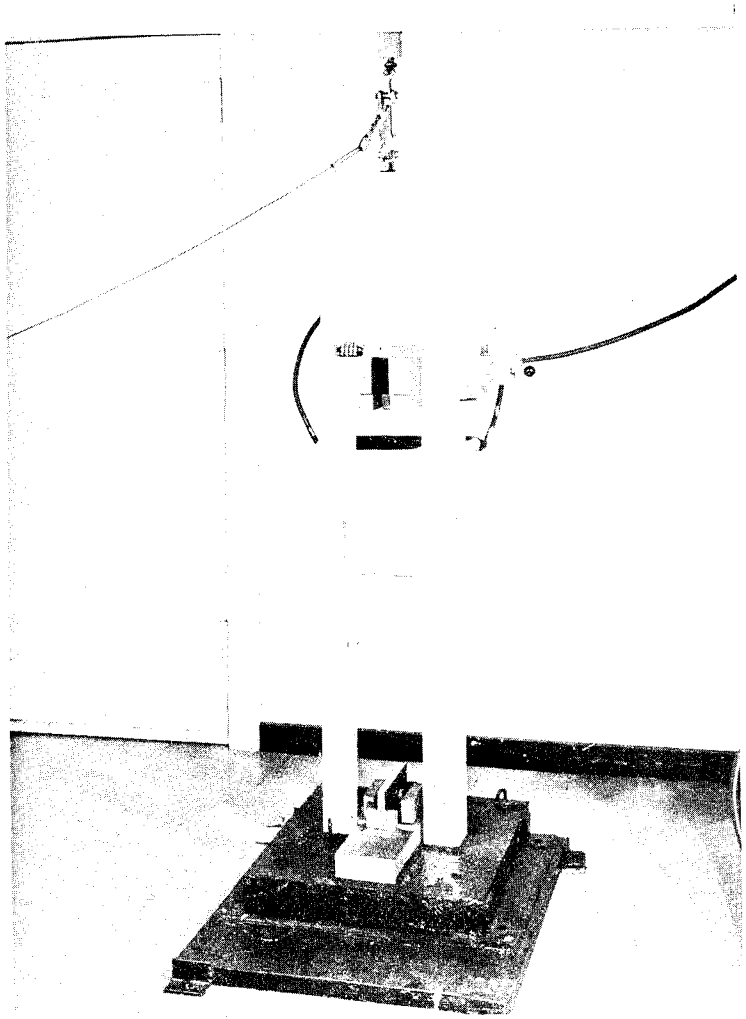

Fig. 1 - A 2000 ft-lb vertical tear test apparatus featuring a removable hammer face and variable anvil.

fall before striking the arresting Pb bricks. The angle iron framework also serves as a guide to the falling hammer.

Details of the hammer and anvil designs are shown in Figs. 2 and 3, respectively. The hammers shown in Fig. 2 may be used for either NDT or tear testing simply by changing the striking face. The anvils shown in Fig. 3 may be used with the corresponding hammer of Fig. 2 for either DWT-NDT, DT, or DWTT testing. The dimensions for the NDT anvil are standardized in ASTM Standard E208, and only the major dimensions for the standard P-3 specimen are shown in Fig. 3. The DT and DWTT anvils of Fig. 3 are not fully dimensioned because these tests are not as completely standardized.

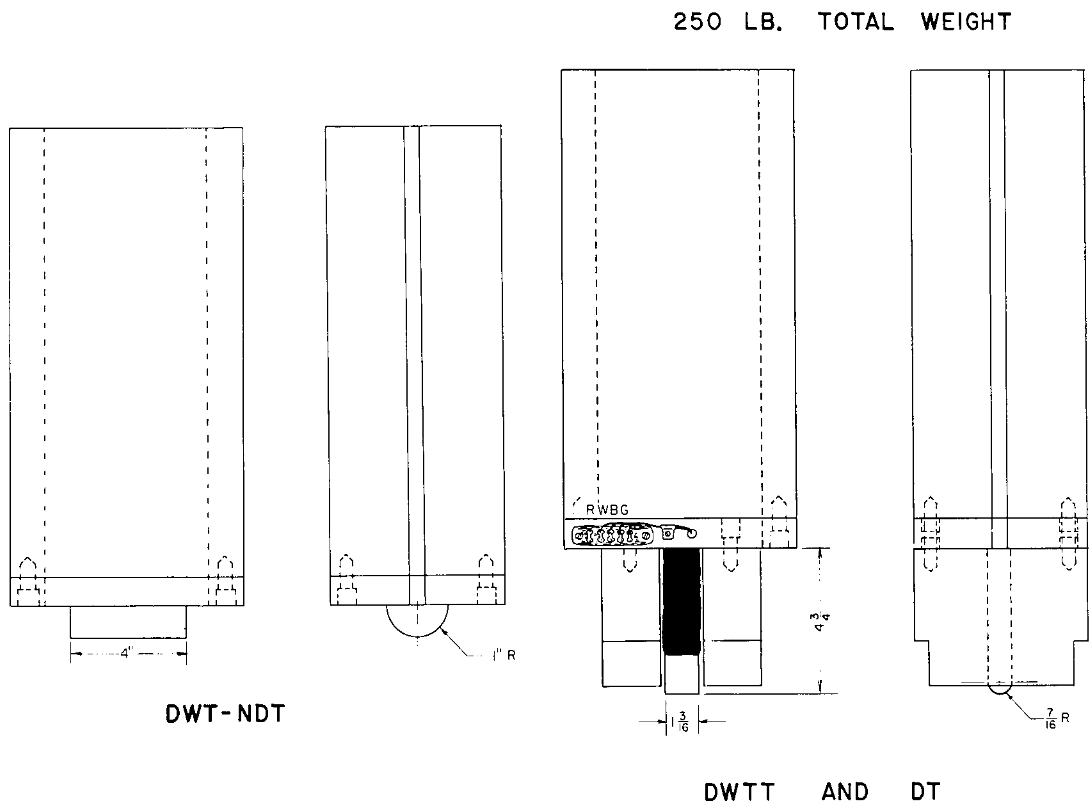

Fig. 2 - These hammer designs for vertical testing feature a removable face which may be instrumented for tear testing or left plain for the nil-ductility test. The symbols RWBG refer to the colors of the lead wire connections.

striking face with dynamic loading of 5/8-in. DT specimens in steels from 35- to 135-ksi yield strength are approximately 20,000 lb.

The anvil in Fig. 3 used for conducting the 5/8-in. DT test has a span of 6-1/2 in., and the anvil for conducting the DWTT has a 10-in. span. The width-to-thickness ratio may be large for the DWTT specimen for thin material, and adjustment guides are required to maintain alignment. These 1-1/2-in. long guides are made from hot-rolled 1/4-in. thick carbon steel angles with 2-1/4 × 4-in. flange widths. Although fracture energy measurements can be made for the DWTT specimen, the specimen is not designed for this purpose. The shallow starting notch and large width do not provide for quantitative analysis of energy data, and therefore the DWTT is used only for establishing transition temperatures. The smaller DT specimen is used for establishing both transition temperature and fracture energy.

ENERGY MEASUREMENT

Instrumentation

The DT energy can be calculated from the load-time profile of the test using the measured impulse (lb-sec) to calculate the change in velocity of the hammer and its loss of kinetic energy. One method for measuring the load on the specimen is to instrument the hammer with a four-arm strain gage bridge formed in the manner shown in Fig. 4.

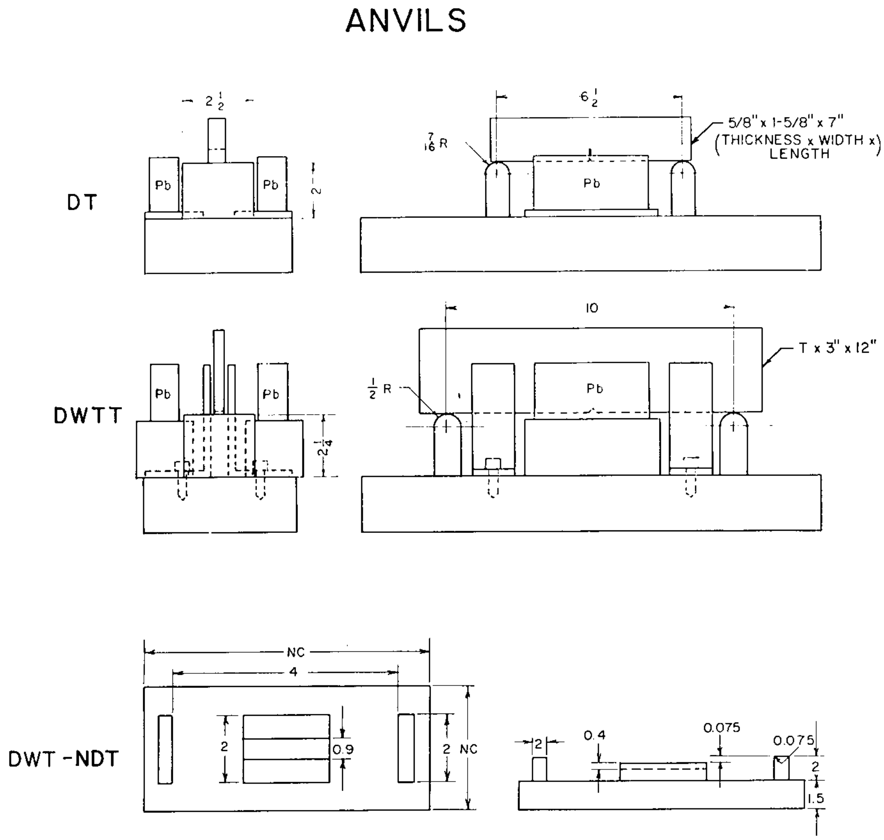

Fig. 3 - Anvil configurations for use with hammers shown in Fig. 2. All dimensions are not shown for the DT anvil (top) and DWTT anvil (center) because the tests are not generally accepted standards.

The means of energizing the bridge and sensing the output are shown in Fig. 5. Essentially, a 6 V Pb-acid storage battery impresses 5 V across the bridge through an on-off switch and a 50-Ω rheostat. Residual output voltage from the bridge is balanced with the 10-Ω potentiometer. The output voltage (green to white) and input voltage (black to red) is channeled by a toggle switch to the digital voltmeter (DVM). This switch is left in the neutral position when a test is conducted to prevent superimposing noise into the oscilloscope. The system is balanced when the voltmeter indicates zero output and the input indication is a precise 5 V.

The electrical output of the transducer shown in Fig. 4 follows the relationship

$$E_o = K\epsilon V$$

where E_o = output voltage, K = gage factor, ϵ = total avg. bridge strain, and V = excitation voltage.

Two potential sources of error in the bridge output are the lead wire resistance and the transducer temperature when one gage is used, or when the thermomechanical properties of the gage are not matched to the hammer material. If the lead wires for a full bridge as shown in Fig. 5 are of equal but nominally small resistances, they exert no significant effect on the bridge output. The output leads to the oscilloscope and/or DVM

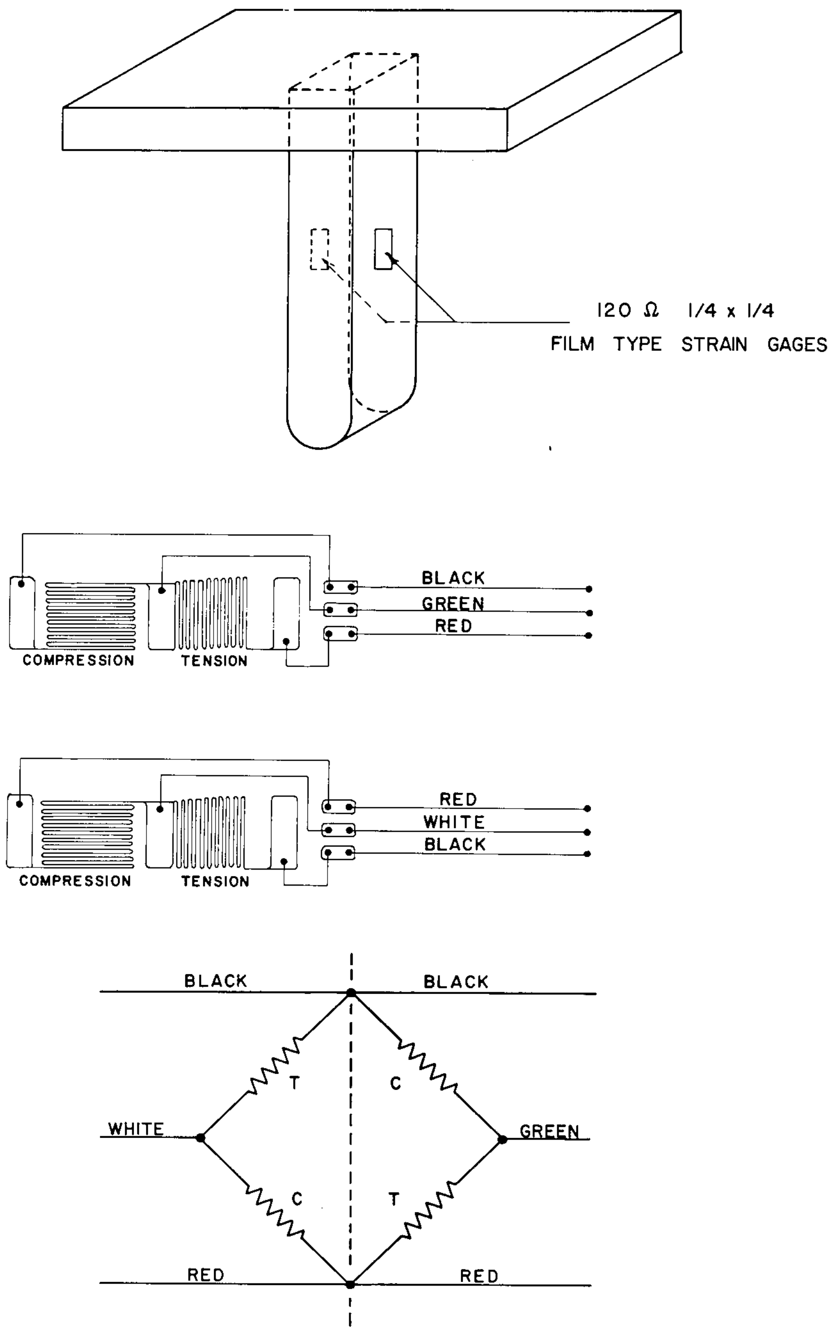

Fig. 4 - Bridge configuration on the instrumented hammer. Four 120-Ω foil gages arranged in two 90° rosettes are mounted symmetrically on the 7/8-in. sides. The colors refer to the same lead wire connections indicated by RWBG in Fig. 2.

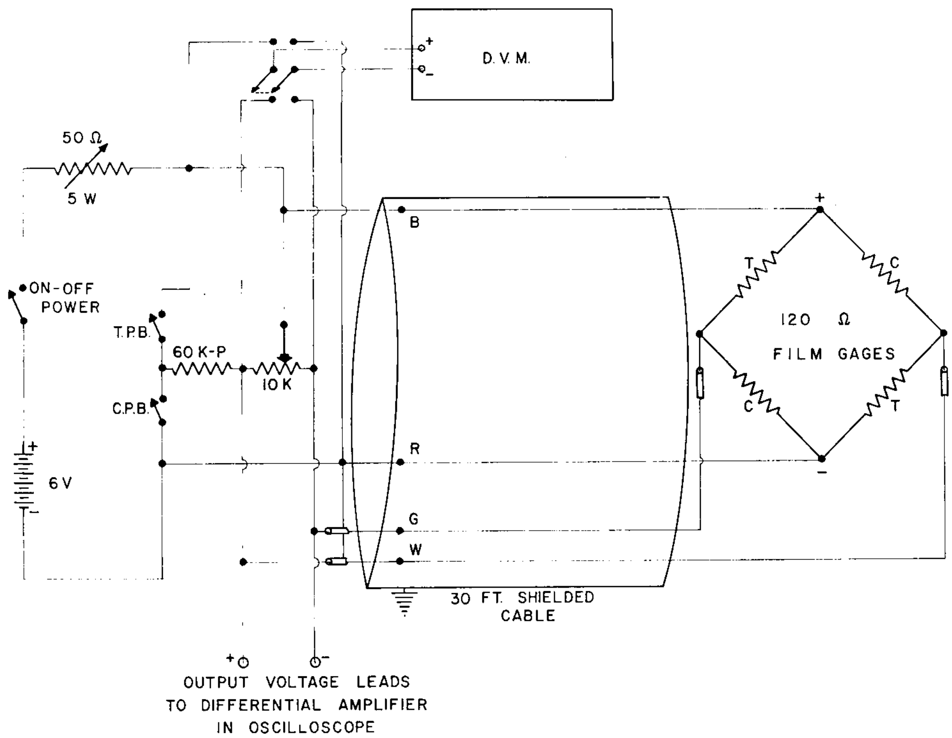

Fig. 5 - Electrical balance and recording system. Five volts are impressed across the bridge with the rheostat and switch. The 10-Ω potentiometer adjusts the output to 0 V when no load is applied to the bridge.

should be coaxial lines of equal length in order to reduce noise pickup. The oscilloscope and the DVM draw negligible currents; therefore, even with the 30-ft cable connection (Fig. 5) the potential difference between points W and G can be considered equal to the bridge output. The instrumented hammer and cable are kept within doors where ambient operating temperatures range between 65° and 85°F, and in this temperature range the gage is matched to the hammer material for thermal expansion characteristics so that any drift in output due to a change in temperature is also of no consequence.

A resistor placed in shunt across any arm in the bridge has the effect of producing an average strain for all four gages. A precision resistor of 60 KΩ simulates 1000 μin. of strain with a single gage having a gage factor of 2.0. This calibration provides an electrical output of 2.5 mV which can be used to standardize the recording circuit and oscilloscope. The two pushbutton switches labeled T.P.B. and C.P.B. shown in Fig. 5 provide this voltage output to the oscilloscope for calibration purposes. When the switch is in the C.P.B. position, the 60-Ω precision resistor is placed in parallal (shunt) with the tension gage between points W and R. This connection in effect lowers the resistance of bridge arm WR. As a decrease in resistance is normally caused by a compressive load on a gage, the decrease in resistance of the entire arm forms a compressive calibration, with a negative output of 2.5 mV. Alternately, when the T.P.B. switch is closed, the 60-kΩ resistor is connected across the compression gage between points B and W. This connection simulates the effect of additional compression in BW, and a positive output of 2.5 mV results.

For static calibration and dynamic measurement, the floating output between points B and W is conditioned and monitored by an oscilloscope with a high-gain differential amplifier. The oscilloscope is set to trigger on the vertical input, and the horizontal sweep time is set to record the entire event. A Polaroid camera records the trace on the oscilloscope.

The relationship between bridge output and applied load is obtained by calibrating the entire system. Specific loads are applied with a universal testing machine or other calibrated loading device, and a dummy specimen of the same width as the intended specimen is placed as a load coupler between the hammer striking face and the compression head of the testing machine. The bar transmits the load to the instrumented hammer in the same manner as a specimen. This is important, especially when the striker is either short or considerably wider than the specimen. A calibration curve is shown in Fig. 6 for the hammer with the dimensions shown in Fig. 2. Precise linearity is noted, which is a requirement for simplified computation of impulse from the force-time record.

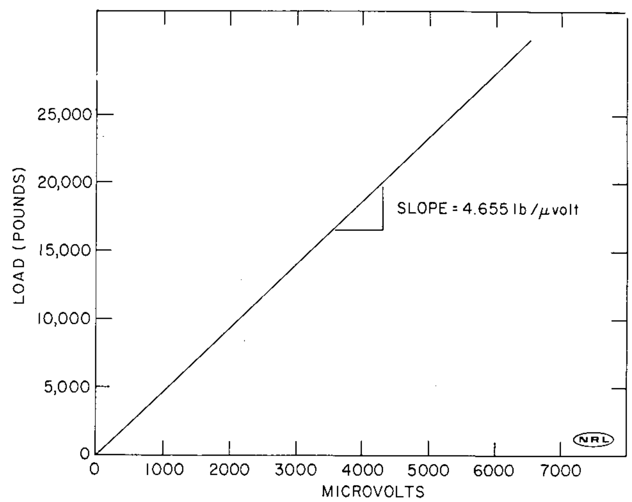

Fig. 6 - Calibration curve for instrumented hammer striking face. The ambient (70-80°F) pressure-voltage relationship is recorded, as shown, after several load excursions indicate constancy from the bridge output.

Energy Calculations

The area under the oscilloscope trace and the following formula provide one method for determining a tear energy measurement:

$$E = I\,(V_o - I/2m)\,,$$

where E = fracture energy, m = mass of hammer (lb-sec^2/ft), V_o = impact velocity, and I = impulse (lb-sec). The impulse I is calculated from the area under the force-time oscilloscope trace using the relationship

$$I = 100 \times \left(\frac{\text{trace area}}{\text{grid area}}\right) \text{Div}^2 \times \frac{\text{msec}}{\text{Div}} \times \frac{\text{mV}}{\text{Div}}$$

$$\times \frac{\text{sec}}{10^3\ \text{msec}} \times \frac{\text{lb-calibration}}{\text{mV}}\,.$$

Each trace area is determined with a compensating polar planimeter and, using the oscilloscope settings and striker calibration factor in the above equation, the impulse term is calculated. Fracture energy is then calculated from the remaining portions of the basic equation.

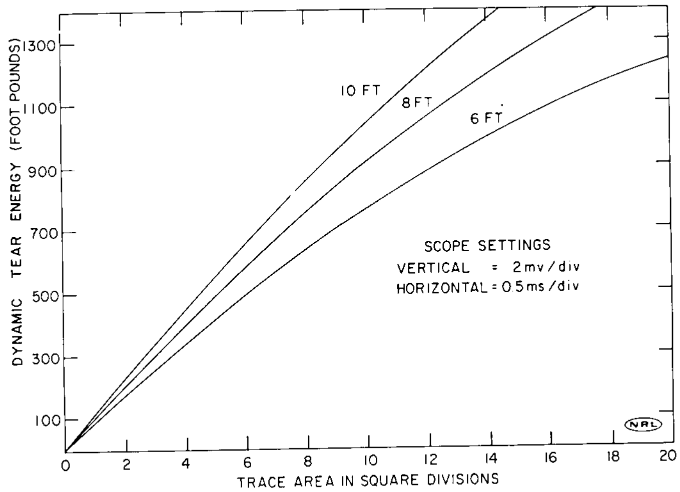

Fig. 7 - Alternate means for tear energy determination. For a constant scope setting and drop height (10, 8, and 6 ft), energies may be read directly once the trace areas are known. Different scope settings would result in curve family variations.

Another method for determining DT energy from an oscilloscope trace area is illustrated in Fig. 7. A family of curves is plotted for a fixed set of normally encountered recording conditions, and DT energy is obtained by graphical interpolation. This graphical method simplified DT energy determination for production purposes since only the trace area need be measured. Care must be exercised in plotting the curves and making the initial calculations. However, once the curves are established this is a rapid and simplified means for energy determination.

DT Energy Using Lead Bricks

The DT energy may also be determined from a measurement of residual energy using lead (Pb) compression bars as illustrated in Fig. 2. The amount of compression is a consequence of the drop height and the amount of energy used to fracture the specimen. To obtain the DT energy, the energy absorbed by the lead bars is subtracted from the input initial energy. This requires a calibration for Pb brick compression as illustrated in Fig. 8, which was obtained experimentally by dropping the hammer directly on the bricks from various heights. Other materials which feature a calibrated collapse with input energy can be used as a substitute for the Pb bricks, e.g., short sections of aluminum extrusions or thin-walled tubing.

During fracture testing, DT energy obtained from the brick compression value is assumed to account for the energy lost in fracture. Actually, energy is also imparted to the specimen through plastic indentation when the striking face contacts the specimen and imparts translational and rotational energy to the fractured halves. Since the DT energy value is an empirical value and interpretative procedures are not influenced by these indirect energy losses, the measured difference in kinetic energy of the hammer is considered as DT energy.

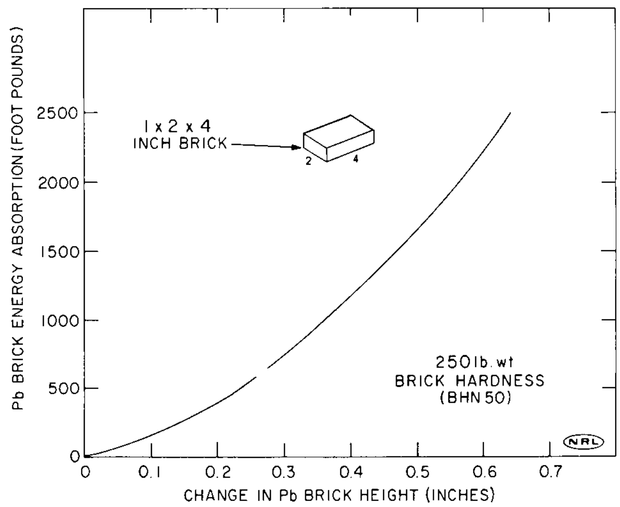

Fig. 8 - Lead (Pb) compression bar calibration curve. The change in brick height is the average of both bricks.

Commercially pure lead is cast in steel molds, without mold wash, to form 2×4×8-in. bricks. Brick hardness is specified at BHN 50. To maintain uniform brick density, only the bottom portion of the castings are used. This procedure minimizes variability in density caused by shrinkage in the top portion of the casting.

A comparison of fracture energy as determined by the impulse technique and the residual energy technique is made in Fig. 9. The energy values shown in Fig. 9 were obtained from 3/8-in. thick DWTT specimens, but a comparable correlation would be expected for DT specimens. The figure reveals how the energy measuring techniques compare as a function of fracture resistance. The linear relation, with a 10% scatter band, indicates that good engineering accuracy can be obtained with either technique for measuring fracture energy.

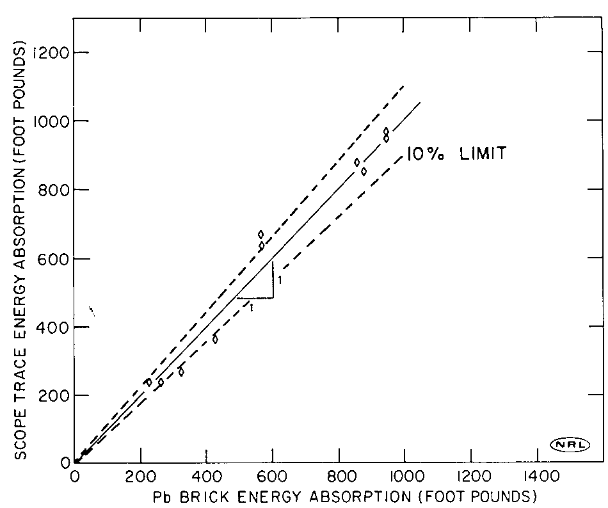

Fig. 9 - Transition temperature correlation for the two methods of tear energy determination. Energies are from a 3/8-in.-thick A-36 steel broken in the DWTT test. The one-to-one correspondence (to within 10%) indicates that good accuracy may be obtained with either method.

CONCLUSIONS

The versatility of a 2000 ft-lb capacity vertical impact test machine has been demonstrated. This machine can be used to conduct DWT-NDT, DWTT, and 5/8-in. DT tests. Although a vertical impact machine is not as efficient for the testing of large quantities of tear test specimens of one design as a pendulum impact machine, it can be useful and a more practical machine to use where versatility is required for a limited number of tests.

Dynamic tear energy can be obtained from the force-time records of an instrumented hammer or from the deformation of calibrated lead bricks. The two methods compare favorably with respect to accuracy of measurement, and either method provides a dynamic tear energy value with the accuracy required for engineering decisions based upon a measurement of fracture resistance.

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